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A Comprehensive Assessment of Water Quality and Mass Balance of the Bhairab River, Khulna

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Abstract: Water is a vital component for all organisms on Earth. Water is essential for the survival of all living organisms on Earth. Water is vital for life, much like oxygen, since no kind of life can survive without it. Water often includes several physical, chemical, and biological contaminants. Surface water sources mostly consist of rivers, lakes, ponds, glaciers, and precipitation. The sources are becoming degraded due to contemporary urbanization, escalating population, domestic trash, and industry. The Bhairab River is not far from the sick worry. The water quality of the area is rapidly deteriorating due to the significant influx of contaminants it gets. This research focuses on evaluating the water quality and mass balance of the Bhairab River. In order to achieve the current objective of the research, a stretch of 22.9 kilometers from Jailkhana Ferighat to Shuvorada Kheya Ghat, Fultola, was split into 10 sample sites. The water samples were collected monthly from each monitoring site during the year of 2021 for laboratory analysis. A total of nine water quality indicators, including Fecal Coliform, Temperature, Biochemical Oxygen Demand (BOD), pH, Turbidity, Total Solids (TS), Phosphate, Dissolved Oxygen (DO), Nitrate, and Chloride, were analyzed using standardized methods. The water quality evaluation was conducted by calculating the WQI using the National Sanitary Foundation (NSF) technique. The mass balance has been determined by means of analysis. The current study is being undertaken using both primary and secondary data sources. The investigation reveals that the primary parameters exhibit varying degrees of correlation with each other. In December, the temperature reached a minimum of 16.8 °C, while in May, it peaked at 37.5°C. The pH reached its peak at 8.80 in August, while it had its lowest point at 7.94 in January. The pH variation is minimal and similar throughout the board. The measured turbidity level was 564 NTU, which is the average value. The maximum total solids (TS) concentration recorded was 3346 mg/L, while the minimum concentration was 2460 mg/L. The phosphate content reached its peak at 8.12 mg/L in S5, while it was at its lowest at 4.26 mg/L in S4. The maximum nitrate concentration measured was 26.4 mg/L, while the minimum concentration was 12.80 mg/L. The maximum biochemical oxygen demand (BOD) recorded was 1.80 mg/L at location S6, whereas the minimum BOD was 0.60 mg/L at location S3. The concentration of BOD was consistently low during each month. The highest fecal coliform (FC) concentration observed in November was 1024 N/100ml, while the lowest concentration was 572 N/100ml. The drinking water quality standard for fecal coliform (FC) in Bangladesh is zero per 100 milliliters. The greatest, average, and lowest values surpass the allowable limit set by BDS. The water quality index determined for the year 2021 for Ten Stations has an average value of 43, indicating a similar level of water quality throughout the stations. According to the range of NSF water quality index, the Bhairab River has a poor quality rating. Therefore, this water is not safe for drinking without undergoing treatment. The Bhairab River has a Mass Balance value of 362349.09 gallons per day.
Keywords: Bhairab River, WQP, Mass Balance, WQI, Khulna, NSF

I. INTRODUCTION

Approximately 66.6% of the surface of Earth is comprised of water, whereas the human body is composed of approximately 75% water. H2O is a vital component for sustaining life. Humans coexist with water and get sustenance from it. It serves as a reservoir of aesthetic pleasure, awe, tranquility, and rejuvenation. It is a valuable and essential natural resource that makes up the main components of an ecosystem. Water sources primarily consist of rivers, lakes, glaciers, rains, and groundwater. In addition, water resources are crucial for fulfilling the requirements of drinking water and are essential for numerous sectors of the economy, including forestry, agriculture, fisheries, cattle production, industrial operations, hydropower generation, and creative endeavors. The accessibility and groundwater are diminishing as a result of significant variables such as rising population, urbanization, and industry. Water is an exceptionally noteworthy item. It is crucial for the survival of all living organisms, including animals and plants. Water is an important component for maintaining cleanliness and hygiene in every setting. Humans may survive for around 60 days without consuming any food, but they can only endure for a period of three to four days without access to water.

The availability of safe and palatable drinking water is crucial for promoting optimal health and well-being within a country. There are primarily two categories of water sources. One water source is surface water, which includes streams, reservoirs, ponds, lakes, rivers, and the ocean. underground, which is the water that stays in the underground table, is the other source. There are three types of impurities that can be found in natural water: biological impurities, live impurities, and waterborne toxins. Dissolved gases, carbonates, sulfates, and sulfides are the main material pollutants.

II. BACKGROUND OF THE STUDY

The Ganges, Brahmaputra, and Meghna rivers of Bangladesh form a huge linked system vital to its people. However, this crucial resource faces considerable challenges. Bangladesh has erratic water resources, with monsoon floods and dry season droughts. Climate change, increasing temperatures, and irregular water patterns increase the nation's vulnerability. Only 1% of Earth's surface has drinkable water, which all life needs. Important rivers and groundwater pour into Bangladesh. However, urbanization, industry, and groundwater arsenic and iron poisoning are degrading river quality.

Growth of towns, businesses, and farmland has exacerbated water contamination. Industrial and urban runoff into waterways is worrying. Chemical pesticides, fertilizers, and other agricultural inputs damage water quality, harming humans and the environment. Given the difficulty of maintaining this critical asset, sustainable water resource management is valued globally. Bangladesh faces this issue because to rising water needs in industry, agriculture, and homes and a growing economy.

Khulna, surrounded by the Rupsha and Bhairab rivers, illustrates this. The waterways are polluted by jute mills, textile mills, power plants, and garbage from homes and businesses. You need to check the water quality of the Bhairab River in Khulna in order to figure out what's wrong and how to remedy it. Due to the complexity of the monitoring systems required for water quality tests, interpreting the results may be a real challenge. In order to facilitate understanding and communication about water quality, water quality indices (WQI) streamline a number of characteristics. The public is provided with straightforward information on water quality via the National Sanitation Foundation (NSF) water quality index.

There are more than just biological, chemical, and physical concerns with water quality. We also need to know how pollution affects ecosystems and people's health.. Environmental bodies like the WHO and EPA set thresholds for numerous parameters to determine water's suitability for ingestion. The study uses the NSF WQI to assess Bhairab River water quality in keeping with the growing demand for sustainable water management. Sustainable fish output, livelihoods, and environmental well-being need effective management.

Bangladeshi rivers face several challenges, including industrial and urban pollution, agricultural activities, and natural pollutants like arsenic. Sustainability, as evidenced by the NSF water quality index, emphasizes the need to preserve this valuable resource for future generations.

A. Objectives and Problem Statements of the Research

Clearly current study encompasses the subsequent objectives:

1) To evaluate the current water quality by analyzing specific criteria related to water quality.
2) To calculate the WQI of the Bhairab River.
3) The objective is to assess the Water WQI and WQP of Bhairab River and compare them with the standards set by the Department of Environment (DoP) and the Environmental Protection Agency (EPA).
4) To conduct a mass balance analysis of the Bhairab River.

B. Scope of the Research:

The notion has a wide range of applications for several reasons. The primary areas of focus are-

1) The study provides a comprehensive grasp of the calibre of water characteristics of the river water.
2) The study focuses on the association of water quality between the chemical and physical properties.
3) Criteria for reducing the intricacy and size of a vast collection of data.
4) The Bhairab River's water quality index will be disclosed.
5) The report provides an evaluation of the Bhairab River and suggests suggestions for managing its water quality in a sustainable manner through correlation.
6) The study will be beneficial for individuals who aspire to pursue additional education in this field.

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III.LITERATURE REVIEW

A. Previous Studies

Bangladesh, a country situated at a low altitude and characterized by a large number of inland water bodies, is very susceptible to the effects of climate change as a result of its geophysical features (Matin et al., 2010). The worldwide period of limited availability of freshwater, driven by population dynamics and higher individual demand, poses substantial difficulties, especially in Bangladesh due to its numerous rivers (Matin et al., 2010).

Emphasizing pivotal research papers establishes a fundamental basis for comprehending the water quality difficulties in Bangladesh:

1) Khan, A.S., Hakim, A., Waliullah et al (2019): Study conducted on the Bhairab River in Khulna to investigate the seasonal fluctuation and water quality. The study revealed that the river experiences Fgreater pollution levels during the summer season.
2) Alam, Md & Badruzzaman, Abu & Ali, Muhammad. (2012). conducted a study on the Sitalikhya River, analyzing changes in water properties. Their findings revealed noticeable disparities in pollution levels between the industrial and non-industrial parts.
3) Alam, MS & Mobin, MN & Alim Miah, Md. (2015): conducted a study to examine the influence of pollutants emitted by the Jamuna Fertilizer Company on the Jamuna River. Their findings indicate that the overall impact of these pollutants is minor.
4) Hadiuzzaman, Md & Baki, Abul B.M. & Khan, Mostafa. (2006): conducted water quality analysis of data for the Balu and Shitalakhya Rivers. Their findings revealed contamination that has an impact on the Saidabad water treatment facility.
5) Kamal D, Khan AN, Rahman MA, Ahamed (2007): conducted a study on the physico-chemical parameters of the Mouri River in Khulna. Their findings revealed significant deterioration, which is cause for concern.
6) Kumar, Pramod & Upadhyay, Hem. (2014): Assessed physico-chemical parameters of the Kosi River, highlighting correlations among different parameters and identifying areas exceeding WHO limits.
7) Rajon. (n.d.). Choudhury (2012): Computed the water quality index for the Faridpur-Barisal road., with a focus on the different values of WQI.
8) Uddin, M. G., Nash, S., & Olbert, A. I. (2021): Discussed various water quality methods, comparing their merits and demerits.
9) Mishra, Shri Prakash. (2019**):** Studied the Gomti River in Uttar Pradesh, establishing positive correlations among key physico-chemical parameters.

B. Study Area Overview

Detailed insights into Khulna, Bangladesh, set the stage for understanding the local context:

1) *Demographics and Industrial Landscape:*
   a) Population estimates for Khulna in 2010.
   b) Diverse occupations contributing to the region's economy.
   c) Rapid industrial growth and associated environmental challenges.

2) *Environmental Challenges and Industrial Expansion*
   a) Degradation of Khalishpur and Daulatpur's ecosystems caused by factories.
   b) Rise in the number of industrial units impacting the Bhairab River.
   c) Key industries contributing to environmental issues.

3) *Water Pollution and Impact*
   a) Specifics on industrial waste affecting Bhairab River water quality.
   b) Environmental impact of shrimp processing factories
   c) Study Area and River System

C. Study Area and River System

Exploration of the study area, focusing on Khulna City Corporation to Fultola, the tropical climate, and river dynamics:

1) *Climate and River Dynamics*
   a) Description of Khulna's climate and its classification.
   b) The study area's location is surrounded by the Bhairab, Rupsha, and Pasur rivers.

2) *Bhairab River and Water Quality Parameters*
a) Bhairab River's origin, course, and length.
b) Examination of ten water quality parameters and their effects on aquatic ecosystems.

3) *Environmental Impact and Human Activities*
a) Human and industrial activities contribute to environmental issues.
b) Land uses surrounding the Bhairab River impacting water quality.

D. Water Quality Parameters

A concise overview of key water quality parameters:
a) Nitrate (NO_3)
b) Biochemical Oxygen Demand (BOD)
c) Chloride (Cl)
d) Fecal Coliform (FC)
e) Dissolved Oxygen (DO)
Correlations among Water Quality Parameters

E. River Ecology

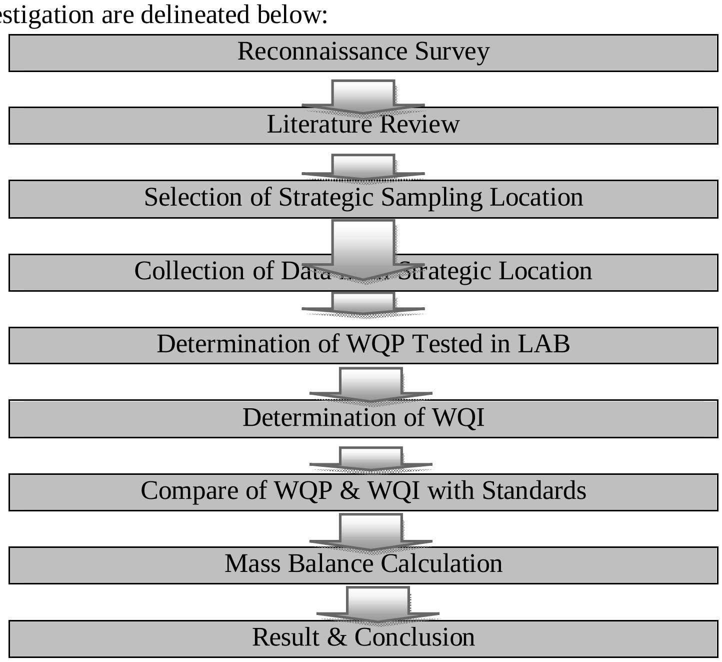
Insights into the factors influencing river ecology:
Water flow strength, light availability, and temperature variations.
A brief recap emphasizing the multifaceted nature of water quality parameters, interconnected factors influencing river ecosystems, and the need for sustainable practices.
Acknowledging of the environmental challenges in Khulna and the importance of understanding and mitigating these challenges for sustainable development. This step-wise structure ensures a clear and organized presentation of the literature review and study area overview.

IV. METHODOLOGY

The "Aquatic Sentinel Approach" involves a sequence of well-defined steps to comprehensively assess water quality and environmental dynamics. Each phase contributes to a holistic understanding, ensuring the thoroughness of the study.

A. Research Strategy

The sequential actions of this investigation are delineated below:



B. Chronological Activities

1) Inceptive Reconnaissance

- Initial survey to understand the study area's nuances.
- Identifying key environmental features influencing water quality.
- Identifying key environmental features influencing water quality.

2) Literature Synthesis

- In-depth review of existing studies and scholarly work.
- Gaining insights into historical data and research trends.

3) Strategic Sampling Site Selection

- Careful identification of locations representing the ecosystem.
- Ensuring diverse representation for a robust analysis.

4) Data Collection from Strategic Nodes

- Systematic water samples were collected from the selected strategic sites.
- Capturing variations reflecting the overall water quality dynamics.

5) Laboratory Determination of Water Quality Parameters (WQP)

- Rigorous testing in the laboratory for key parameters.
- Employing precise methods to ensure accuracy.

6) Water Quality Index (WQI) Calculation

- Utilizing established formulas to compute the WQI.
- Aggregating diverse parameters into a unified index.

7) Comparison with Standards

- Scrutinizing WQP and WQI against established standards.
- Identifying deviations and potential environmental risks.

8) Mass Balance Calculation

- Quantifying the distribution and movement of pollutants.
- Assessing the overall impact on the aquatic ecosystem.

9) Results and Conclusion

- Presenting findings derived from the cumulative analysis.
- Drawing conclusive remarks on water quality and environmental health.

The "Aquatic Sentinel Approach" embodies a meticulous process ensuring a comprehensive evaluation of water quality. By amalgamating advanced laboratory techniques with strategic site selection, this methodology aims to serve as a sentinel for aquatic ecosystems, providing valuable insights for sustainable environmental management.

C. Selection of Study Area

Ten sampling stations were carefully chosen with a focus on convenient accessibility and maintaining relatively equal intervals. These stations span from Jailkhana Ferry Terminal to Fultala Bazar Ghat, and their corresponding IDs (S1 to S10) can be found in Table. The study area along Bhairab River covers a length of approximately 22.9 km.

Figure 1: The precise geographic location of the Bhairab River.

D. Selection of Study Area

Station ID	Sampling Location	Latitude	Longitude
S1	ShuvoradaKheyaGhat	22°48'2.22" N	89°34' 58.52" E
S2	Dhul Gram KheyaGhat	22°49'27.39" N	89°33' 36.08" E
S3	Bhairab-Maidhukhali River Mohona	22°51' 17.80" N	89°33' 12.87" E
S4	Cable Ghat - Shiromoni BRTA	22°52' 13.36" N	89°39' 12.78" E
S5	Ralligate Ferry Terminal	22°54'30.34" N	89°31 '8.28" E
S6	DaulatpurKheyaGhat	22°56'26.43" N	89°29'43.5 I" E
S7	Senhati Union PorishodBaak	22°58'30.4 I" N	89°28'42.77" E
S8	CharerHat - Bhairab-AtaiMohona	23°0'34. I 4" N	89°2T33.2 I" E
S9	7 No Custom Ghat	23°0'28.0 I" N	89°25'24.84" E
S10	Jailkhana Ferry Terminal	23°1 '54.63" N	89°23' 58.69'. E

E. Gathering Water Samples

Throughout the year 2021, samples were systematically gathered from specified stations depicted in Figure 3.2 on a monthly basis. Special care was taken in selecting the optimum time in accordance with the environmental conditions. Each sample was collected in a 1-liter polypropylene container that had been thoroughly rinsed with a mixture of diluted alcohol and hot distilled water, and then dried in an oven. The required quantity for testing was obtained by combining water from three separate locations into a homogenous combination. The NWU Environmental Engineering Laboratory stored the specimens and tested them thoroughly as needed.

F. Water Sampling Depth

Water samples were taken at several locations, namely at depths between 30 and 45 meters below the water's surface.

G. Water Sample Labelling

Because time changes test results, it is very important that samples are labeled correctly. The following order is clearly written on each container's label:

1) Date and Time
2) Sample Number
3) Sampling Stations

H. Preserving Water Samples

To prevent air from being trapped within, samples were placed into plastic bottles and meticulously sealed. In addition, samples were kept cool in an icebox throughout collection, particularly during warmer weather.

I. Laboratory Testing of Parameters

Water samples from the Bhairab River were tested for a variety of physical, chemical, and biological characteristics in order to get a better understanding of the river's water quality. Some of the physical test parameters were temperature, color, hardness, turbidity, and total solids (TS). The chemical analysis revealed the presence of chloride, dissolved oxygen (DO), biological oxygen demand (BOD), and phosphate. Fermentable coliforms (FC) and total coliforms (TC) were the primary targets of biological testing. At the Environmental Engineering Laboratory at Northwest University, the samples were tested to the limit.

J. Calculating NSF WQI

The Water Quality indicator is a standard indicator developed by the National Sanitation Foundation (NSF). The WQI is quite prevalent across all current water quality methodologies. The collective outcomes of nine distinct assessments may be used to ascertain the characteristics of a specific segment of a river. The water quality index comprises nine significant parameters: Dissolved Oxygen (% Saturation), Fecal Coliform, pH, Biochemical Oxygen Demand (BOD), Temperature Change, Total Phosphate, Nitrates, Turbidity, and Total Solids. The NSF WQI is determined by assigning weights to each individual parameter and calculating the sub-index for each water quality parameter based on their separate testing results.

This may be done using a water quality index calculator. The WQI for each parameter was determined using the WQI calculator developed by the Environmental Engineering and Earth Sciences (EEES) Center of Environmental Quality at Wilkes University. The National Sanitary Foundation (NSF) determines the overall Water Quality Index (WQI) using the following Equation, which is used by the Environmental Engineering and Earth Sciences (EEES) department. The maximum score that a body of water may get is 100.

$$WQI=0.171_{DO}+0.16_{FC}+0.11(1_{pH}+I_{BOD})+0.10(1_{\Delta T}+I_{PO4}+I_{PO3})+0.081_{T}+0.07I_{TS}\text{....................}(1)$$

The individual water quality sub-index is represented by the variable "I", and the weighting factors for each individual parameter are denoted as "coefficient". The WQI has been determined using equation (1). To determine the overall Water Quality Index (WQI) when less than nine parameters are measured, the data may be summed and then adjusted based on the number of tests conducted. For instance, the measurements for BOD and temperature are not accessible; thus, the sum of the seven remaining sub-totals is calculated, as well as the sum of the seven weighting factors. Next, the former value is divided by the later value to get the desired WQI, which is represented by the equation WQI = Sum of individual water quality index / Sum of weight factors.

The Water Quality Index is a numerical value that represents the overall quality of water at a certain site based on many characteristics. It simplifies complicated water quality data into information that can be easily understood and used by the general public (Rumman et al., 2012). A Water Quality Index (WQI) aims to provide a method for quantitatively representing a certain level of water quality, based on cumulative data (Miller et al. 1986).

Table 1: The Water Quality Index Ranges are follows

WQI Range	Water Quality
0-24	Very Bad
25-49	Bad
50-69	Medium
70-89	Good
90-100	Excellent

K. Mass Balance Equation

The Materials Balance, often called the Mass Balance, is a mathematical model of the flow of materials into, out of, and within a system with well defined boundaries.

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The Mass Balance Equation is bellow -

P + QIn = ET + ∆S + QOut

Where,

P = Precipitation
Q In = Catchment Inflow
Q Out = Catchment Outflow
ET = Evapotranspiration
∆S = Change in Mass Storage

V. RESULTS AND DISCUSSION

This research stands out as a pivotal segment with its primary objective being the presentation and analysis of the water quality of the Bhairab River through various methodologies. Key tasks encompass evaluating river water quality through graphical representation, calculating temporal and spatial water quality indices, determining the overall WQI using the NSF method, projecting WQI trends, and forecasting chloride movement over time. Additionally, the chapter involves establishing correlations among water quality parameters, presenting and interpreting a multitude of primary and secondary data, and discussing their formulation and calculations.

A. *Experimental Results*

The table below details the stream width, average depth, river area, velocity, and discharge at different station points. The minimum and maximum stream widths were observed at S10 and S1, respectively. S9 exhibited the highest average depth, while S2 recorded the minimum. Total Station was utilized to determine the river area, with the maximum area measuring 2846.58m and the minimum at 573.67m. The velocity of each station point was determined using the floating method, revealing a range from 0.22 to 0.97, with the maximum and minimum readings identified.

Table 2: Characteristics of Water Sampling Stations

ST NO	Stream Width	Average Depth	Area of River (m^2)	Velocity (Meter/Second)	Q (m^3/Sec)
S1	139.23 M	4.12 M	573.6276	0.875	501.92415
S2	147.97 M	3.97 M	587.4409	0.88	516.947992
S3	202.64 M	11.7 M	2370.888	0.97	2299.76136
S4	184.07 M	6.35 M	1168.8445	0.63	736.372035
S5	164.18 M	6.9 M	1132.842	0.223	252.623766
S6	141.84 M	7.9 M	1120.536	0.29	324.95544
S7	166.11 M	6.85 M	1137.8535	0.62	705.46917
S8	231.81 M	10.5 M	2434.005	0.74	1801.1637
S9	216.47 M	13.15 M	2846.5805	0.58	1651.01669
S10	242.92 M	9.6 M	2332.032	0.69	1609.10208

B. Results & Discussion of WQP

An evaluation was conducted to find out the water quality Bhairab River based on twenty factors.

The following are the results:

1) Temperature

In May, it reached 37.5°C (too high), and in December, it was 16.8°C (also too high). Except for these months, it's okay for drinking but not in May or December. It's fine for other uses throughout the year.

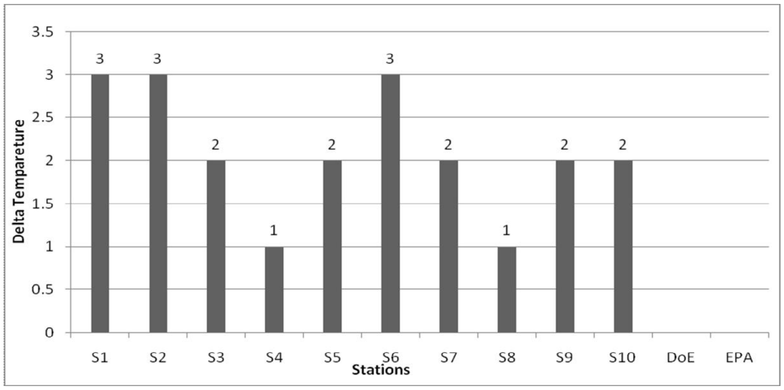

Figure 2: Variation of Delta Temperature at Different Station

2) pH

Ranges from 7.94 (lowest in January) to 8.80 (highest in August). All are within the permissible range for consumption and other applications.

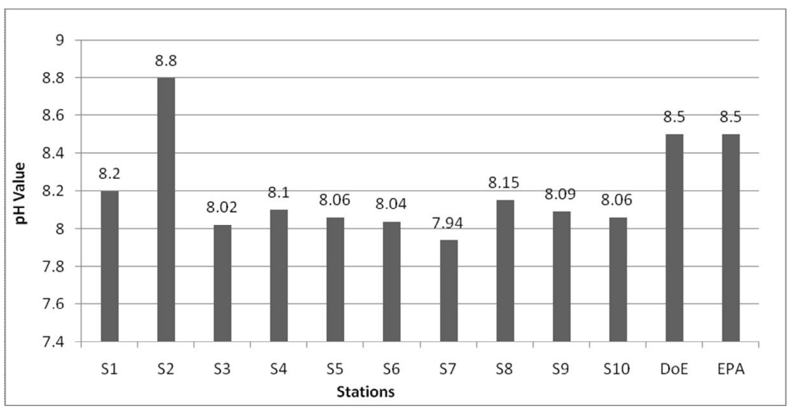

Figure 3: Variation of pH at different stations with Standard Value

3) Turbidity

The average was 564 NTU, with a high of 826 NTU and a low of 438 NTU. The water is unsuitable for consumption because to its high turbidity levels, however it may be utilized for recreational activities, irrigation, and fishery.

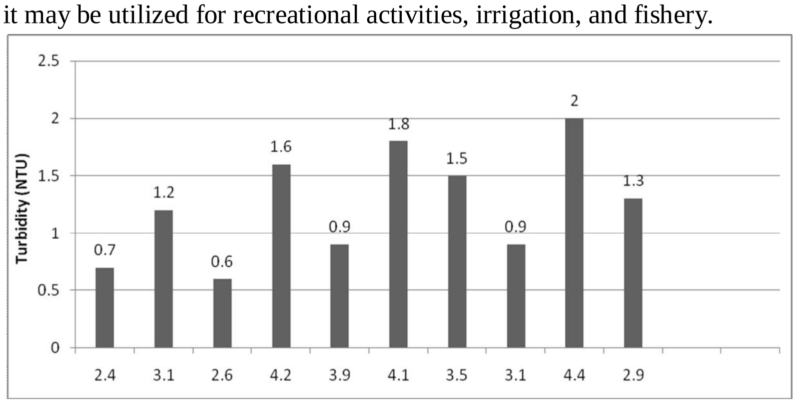

Figure 4: Variation of Turbidity at Different Stations with Standard Value

4) Total Solids (TS)

The range spans from 2460 mg/L to 3346 mg/L. The consumption varies seasonally, but there is no explicit restriction on drinking.

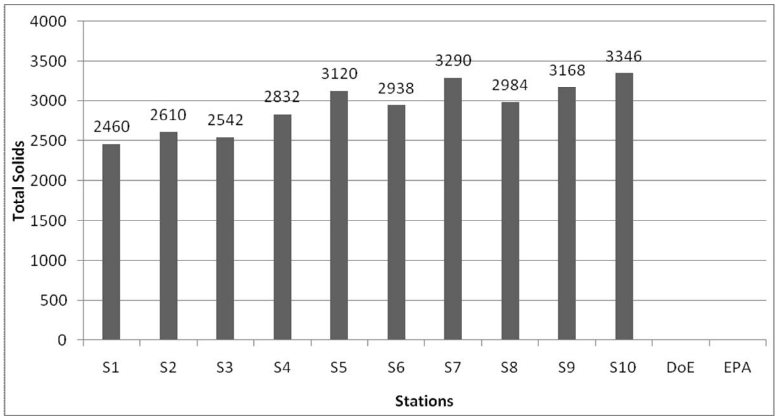

Figure 5: Variation of TS at Different Stations

5) Phosphate

Ranges from 4.26 mg/L (minimum) to 8.12 mg/L (maximum). Always exceeding the maximum allowable alcohol consumption level, but can be utilized for any purpose depending on the quantity of phosphates.

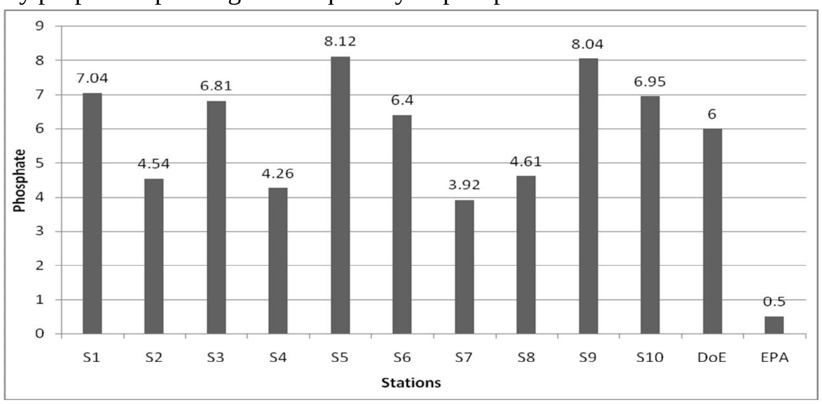

Figure 6: Variation of Phosphate at Different Stations with Standard Value

6) Nitrate

Ranges from 12.80 mg/L (lowest) to 26.4 mg/L (highest), exceeding the safe drinking limit. However, it's fine for other purposes.

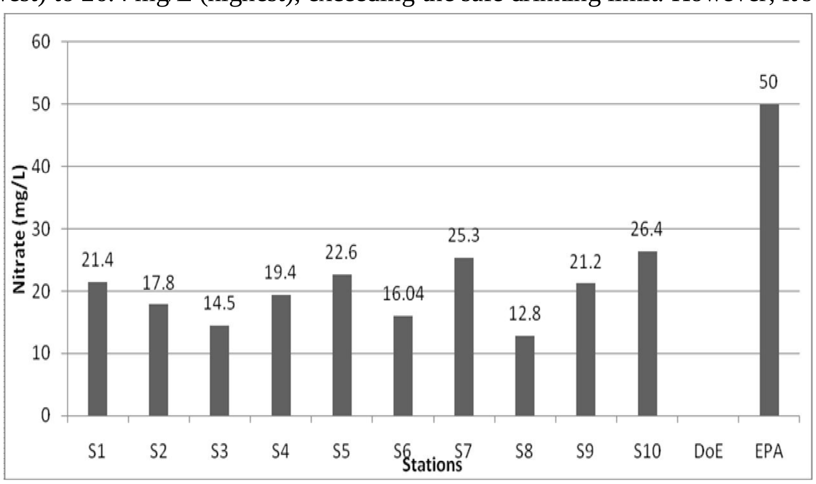

Figure 7: Variation of Nitrate at Different Stations with Standard Value

7) Bio-Chemical Oxygen Demand (BOD)

The highest BOD was 1.80 mg/L and the lowest BOD was 0.60 mg/L. It indicates sewage pollution and is not suitable for drinking.

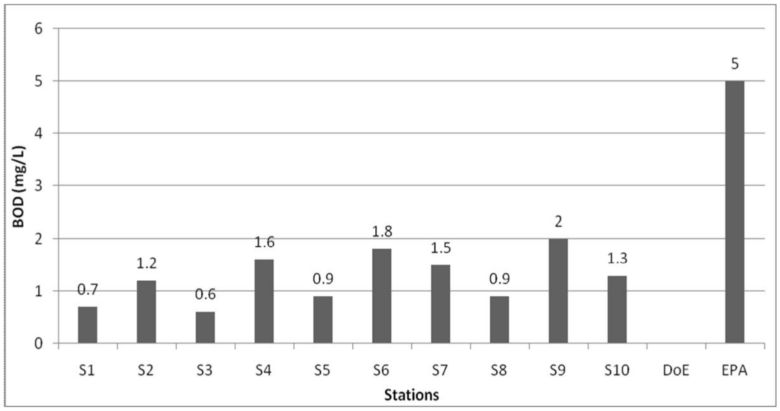

Figure 8: Variation of BOD at Different Stations with Standard Value

8) Fecal Coliform (FC)

Fluctuates monthly, with the highest at 1024 N/100ml and the lowest at 572 N/100ml. Exceeds the limit for drinking but might be usable for other purposes despite sewage pollution.

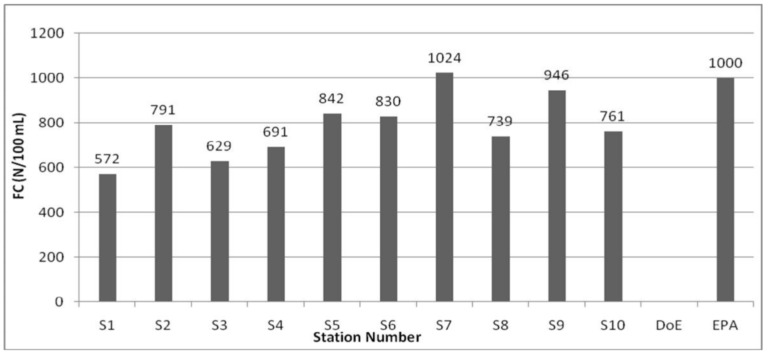

Figure 9: Variation of Fecal Coliform at Different Stations with Standard Value

Table 3: Water Quality Parameters of Bhairab River

Parameter	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
DO (mg/L)	2.4	3.1	2.6	4.2	3.9	4.1	3.5	3.1	4.4	2.9
BOD (mg/L)	0.7	1.2	0.6	1.6	0.9	1.8	1.5	0.9	2	1.3
TS (mg/L)	2460	2610	2542	2832	3120	2938	3290	2984	3168	3346
Nitrate (mg/L)	21.4	17.8	14.5	19.4	22.6	16.04	25.3	12.8	21.2	26.4
Turbidity (NTU)	438	524	641	482	742	826	593	638	739	581
pH	8.2	8.8	8.02	8.1	8.06	8.04	7.94	8.15	8.09	8.06
Delta Temperature	3	3	2	1	2	3	2	1	2	2
Phosphate (mg/L)	7.04	4.54	6.81	4.26	8.12	6.4	3.92	4.61	8.04	6.95
FC (NOS/100 mL)	572	791	629	691	842	830	1024	739	946	761

The investigation shows that out of ten parameters, seven averaged values exceeded permissible limits, while three stayed within. Comparing standard drinking values with experimental ones, Turbidity, Chloride, FC, and TC surpassed safe drinking limits. Table details the test results for pH, DO, BOD, TS, Nitrate, Turbidity, Delta Temperature, Phosphate, and FC of Bhairab River. Lab results indicate pH ranged from 7.94 to 8.8, DO from 2.4 to 4.4, BOD from 0.6 to 1.8, TS from 2542 to 3346, Nitrate from 12.8 to 26.4, Turbidity from 438 to 742, Delta Temperature from 3 to 1, Phosphate from 3.93 to 8.04, and FC from 572 to 1024, respectively.

Table 4: Determined Water quality by the NSF WQI

Sample ID	Overall WQI Score	Water Quality Category
S1	40.46	BAD
S2	40.23	BAD
S3	43.27	BAD
S4	45.84	BAD
S5	42.86	BAD
S6	44.14	BAD
S7	42.81	BAD
S8	44.39	BAD
S9	43.47	BAD
S10	40.35	BAD

Water samples from ten Bhairab River stations were lab-tested, leading to the creation of Table, depicting the water quality index. The average index for 2021 at all ten stations hovered around 43, indicating consistent levels. However, per NSF standards, Bhairab River water quality falls under the "BAD" category, unsuitable for drinking without treatment.

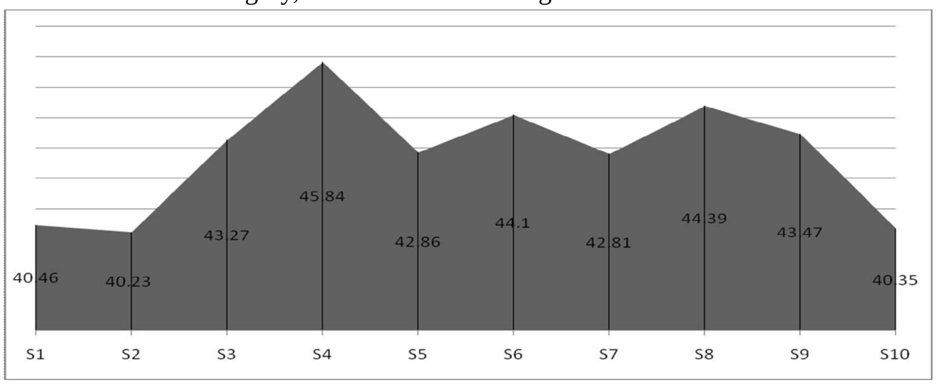

Figure 10:Water Quality Index of Respective Stations

The Water Quality Index curve (Figure) illustrates values for S1 to S10 as follows: 40.46, 40.23, 43.27, 45.84, 42.86, 44.14, 42.81, 44.39, 43.47, and 40.35 respectively. S4 displayed the highest value of 45.84, while S2 had the lowest at 40.23.

The study notes a decline in the water quality index over time. From 2005 (71) to 2014 (64), the index dropped by 7 points, averaging a yearly decrease of 0.70 points. Extrapolating this trend, the projected index for 3050 is 35.65, indicating a shift from Medium to Bad quality, posing a significant concern for the local environment, especially the Bhairab River in the Khulna region.

Using nine parameters (DO, FC, pH, BOD, AT, phosphate, nitrate, turbidity, and total solids), The Table showcases monthly Water Quality Index values for January to December 2021 (40, 41, 43, 45, 42, 44, 43, 44, 43, and 40). Monthly variations were negligible, with April showing the highest index of 45 and December the lowest at 40. The overall index for 2021 stood at 43.

C. Mass Balance and BOD Loading Analysis:

Materials Balance, also known as Mass Balance, quantitatively tracks all materials entering, leaving, and accumulating within a system with defined boundaries. It accounts for water movement within a specified volume or area, adhering to the principles of mass conservation over time.

The Mass Balance Equation of Bhairab River is as Follows-

$$\mathbf{P + Q_{In} = ET + \Delta S + Q_{Out}}$$

$$15 + 43366246.56 = 2 + \Delta S + 139026419.7$$

$$\Delta S = -95660160.14\ (m^3/\text{Day})$$

$$= 362349.09\ (\text{Gallon/Day})$$

Where,

P (Precipitation) = 15 [Bangladesh Meteorological Department, 2021]

Q_{In} = Catchment Inflow
Q_{Out} = Catchment Outflow
ET (Evapotranspiration) = 2
ΔS = Change in Mass Storage

Mass Balance Calculation have been calculated through Analysis. Obtained Mass Balance value of 362349.09 (Gal/Day).

Table 5: Discharge per Day in the Selected Station

Station	Area(m^2)	V (m/Sec)	Q (m^3/S)	Q (m^3/Day)	Q (Gal/Day)
Q_{In} (S1)	573.6276	0.875	501.92415	43366246.56	164266.0855
Q_{Out}(S10)	2332.032	0.69	1609.10208	139026419.7	526615.2262

Table displays the catchment Inflow at S1 and catchment Outflow at S10. Discharge (Q) is calculated by multiplying Area with Velocity. The calculations reveal a Catchment Inflow of 164,266.54 Gallons/Day at S1 and a Catchment Outflow of 526,615.22 Gallons/Day at S10.

Discharge, the water volume in a river or water body, fluctuates over time. BOD concentration in the influent helps calculate the daily BOD load. The formula multiplies the BOD in mg/l by the daily in cubic meters (m3) and divides the product by 1000. Table 4.5 and Figure 4.10 depict the daily discharge and BOD loading rates at ten Bhairab River points from Khulna to Fultola:

- S1: Discharge - 43,366,246.56 m3/day, BOD loading - 36.86 tons/day
- S2: Discharge - 44,664,306.51 m3/day, BOD loading - 37.96 tons/day
- S3: Discharge - 198,699,381.5 m3/day, BOD loading - 168.89 tons/day
- S4: Discharge - 63,622,543.82 m3/day, BOD loading - 54.07 tons/day
- S5: Discharge - 21,826,693.38 m3/day, BOD loading - 18.55 tons/day
- S6: Discharge - 28,076,150.02 m3/day, BOD loading - 23.86 tons/day
- S7: Discharge - 60,952,536.29 m3/day, BOD loading - 51.80 tons/day
- S8: Discharge - 155,620,543.7 m3/day, BOD loading - 132.27 tons/day
- S9: Discharge - 142,647,842 m3/day, BOD loading - 121.25 tons/day
- S10: Discharge - 139,026,419.7 m3/day, BOD loading - 118.17 tons/day

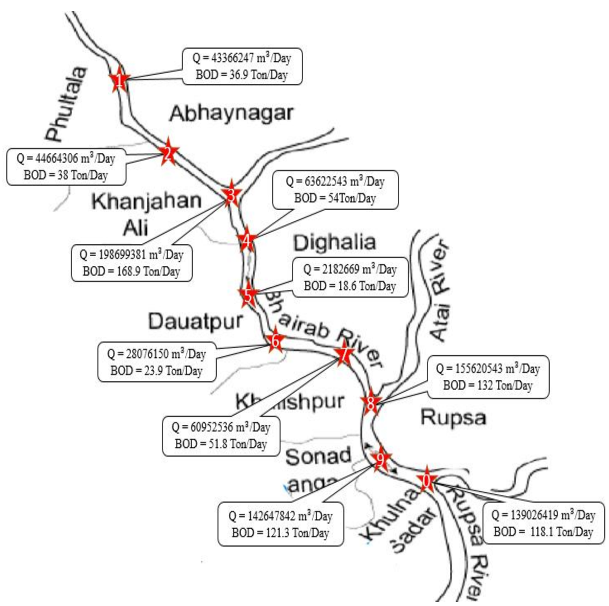

Figure 11: Per Day Discharge & BOD Loading at Each Stations

Here, S3 records the highest discharge of 198,699,381 m^3/day, while S5 exhibits the lowest discharge of 21,826,693 m^3/day. In terms of BOD loading, S3 shows the highest value of 168.89 tons/day, whereas S5 demonstrates the lowest at 18.55 tons/day.

VI. CONCLUSIONS

The study focused on Bhairab River, examining crucial water quality parameters in 2021 across ten sampling locations. It aimed to assess water suitability for designated uses, treatment needs, and pollution levels using the NSF Water Quality Index.

A. Conclusions

1) Of the nine parameters tested, Turbidity, TS, BOD, and FC exceeded standards, while Temperature, pH, DO, Phosphate, and Nitrate remained within limits. Treatment is necessary if the river water is used for drinking.
2) Bhairab River's Water Quality Index indicates poor quality as per NSF standards. Improved parameter control can enhance water management.
3) Comparison of Bhairab River's parameters against DoE, EPA, and NSF standards reveals average to poor quality. WQI decreased from 71 in 2005 to 43 in 2021, signifying a significant decline.
4) Mass Balance analysis yielded a value of 362,349.09 Gallons/Day.

B. Recommendations

1) Remove hanging latrines along the river, especially in Hat-Bazar, or construct sanitary facilities.
2) Treat and monitor industrial and urban sewage before discharge.
3) Implement modern waste management and encourage private sector involvement in recycling.
4) Utilize mass media for public awareness on water pollution causes and impacts.
5) Investigate aquatic species to gauge river health and human safety.
6) Conduct further studies on heavy metals' impact on water quality in Bhairab River.

VII. ACKNOWLEDGMENT

Several recommendations are proposed to address the current state and future study: Removing hanging latrines along the river, particularly in Hat-Bazar, or constructing environmentally friendly facilities is crucial. Industries' and urban sewage systems' effluents should undergo sincere treatment and monitoring before discharge. Implementing modern waste management techniques and encouraging private sector involvement in recycling is essential. Leveraging mass media platforms to highlight water pollution causes and impacts is important. As fish serve as indicators of river water pollution levels, further research on aquatic species is recommended for human health safety and river ecosystem preservation. While this study focuses on the Bhairab River's Water Quality Index and its future trends, further investigations into heavy metals' impact on water quality are encouraged for a comprehensive understanding.

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